Exhaust plumes emanating from smoke stacks at power plants or other industrial facilities can have adverse impacts on local aviation during periods of calm winds. Adverse impacts can be exacerbated if the temperature is low or the atmosphere is unstable. While low oxygen concentrations and elevated temperatures inside the plume can be detrimental to slow-flying or hovering helicopters, the turbulence generated from the upward motion of the plume is the main potential hazard to light, fixed-wing aircraft at low altitudes.

Description of Model

The Exhaust Plume Analyzer consists of three main parts: a convective flow model describing the mean flow of the plume, two aircraft response models judging the required vertical gust to achieve severe turbulence or aircraft upset, and a turbulence model computing the probability of experiencing a gust capable of causing severe turbulence or aircraft upset.

An exhaust plume can be described as a vertical turbulent buoyant jet consisting of two main parts: a momentum-dominated region (jet region) and a buoyancy-dominated region (plume region), as shown in Figure 1. After comparing several models to experimental data (both laboratory and full-scale), the Spillane1 model was found to be the most accurate for these purposes. It can accurately describe the mean flow behavior of the exhaust plume in its various regions for a single stack or multiple aligned stacks.

Two aircraft response models were adopted to determine how aircraft are affected by vertical gusts created by exhaust plumes. The Exhaust Plume Analyzer uses the Gust Loads Formula to predict the vertical gust required to experience severe turbulence, which is defined as a 1g vertical acceleration per the National Oceanic and Atmospheric Administration’s (NOAA) Forecasting Guide on Turbulence Intensity. In addition, the Exhaust Plume Analyzer uses the Houbolt2 roll model to determine the vertical gust that would cause aircraft upset (a bank angle of 45 degrees) if the vertical gust was concentrated...
on the tip of the wing and the flight crew or Flight Management System (FMS) did not take corrective action. Since these aircraft response models require detailed aircraft parameters, the Exhaust Plume Analyzer provides aircraft parameters for four aircraft types representing light-sport aircraft, light General Aviation (GA) aircraft, business jets, and large jets. Furthermore, advanced users interested in modeling additional aircraft have the option to provide parameters for a user-defined aircraft type.

While the Spillane model computes the average plume flow, there could be much stronger turbulent gusts inside the plume. A model derived from the empirical data of Papanicaloau and List was leveraged to determine the likelihood of experiencing a gust that would cause severe turbulence or aircraft upset. By using this combination of models, the Exhaust Plume Analyzer calculates the probability of experiencing severe turbulence or aircraft upset at any point in the vicinity of an exhaust plume.

The behavior of an exhaust plume depends greatly on the local weather conditions. During windier periods, the plume will turn over in the direction of the wind, resulting in a lower risk for experiencing severe turbulence. On the other hand, the risk increases during periods of calm winds as the plume rises uninhibited. Therefore, to accurately portray the likelihood of a severe turbulence or aircraft upset event, it is necessary to examine several years of historical weather data. The Exhaust Plume Analyzer provides the option for the user to query an external MITRE server for hourly atmospheric conditions at a specific location. Three years of weather data are recommended to account for seasonal effects and anomalous weather conditions.

Sample Output

The Exhaust Plume Analyzer was executed over three years of environmental data to calculate the probability of a light GA aircraft experiencing severe turbulence at the Ft. Martin Power Station near Morgantown, WV. As seen in Figure 2, the areas closer to the top of the stack have the highest probability of experiencing severe turbulence. Typically, as the size of the aircraft increases, the likelihood of experiencing severe turbulence or aircraft upset decreases substantially.

Figure 2. The Probability of a Light GA Aircraft Experiencing Severe Turbulence in the Vicinity of the Fort Martin Power Station Near Morgantown, WV
Exhaust Plume Analyzer Access

The Exhaust Plume Analyzer will be hosted through MITRE’s FastLicense process. Interested parties should follow the instructions provided at [www.mitre.org/research/technology-transfer/about-fastlicense](http://www.mitre.org/research/technology-transfer/about-fastlicense) to apply for access to the model.

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